Leigh (E.)

RESPIRATION

SUBSERVIENT TO

NUTRITION.

A THESIS

PRESENTED TO THE

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Hæc universa longe minus faciunt, quam una sanguinis contemperatio à novo aëre per pulmones subinde reciprocato; quæ quidem sola mirum in modum ægritudinem sublevat confestim; quod á me non uno experimento comprobatum est.—*Sydenham*.

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MDCCCLIII.

RESPIRATION

SUBSERVIENT TO

NUTRITION.

BY E. LEIGH, M. D., TOWNSEND, MASS.

Nutrition is the cardinal function of organic life throughout the whole animal kingdom. In the higher animals, and especially in the human system, a great number and variety of functions are subservient to this, all converging towards it as a common centre. Among these may be mentioned mastication, salivation, deglutition, digestion or chymification, chylification, respiration and circulation. Some of these functions, however, such as digestion, respiration and circulation, are common to all animals, even the very lowest. They all must receive, dissolve, elaborate and circulate the materials necessary to build up their tissues and sustain the vital action of all their organs. It is only in the very first period of their life, when they exist in the form of a simple germinal cell, that these subordinate functions appear to be wanting. The nutrition of such a cell-animal would seem to be conducted without any preparatory process, unless the function of respiration be probably associated with it.

In the higher animals the many various functions referred to are, to a great extent, performed each by a separate organ ; so that, in the human system, we find a large number and variety of distinct organs, a peculiar and appropriate office being assigned to each. In the lowest radiata, on the contrary, these functions, or rather so many of them as are essential, are performed by the walls of a single cavity. Thus, in the highest animals, there is a complication of many diverse organs, and each organ is also more or less complicated in itself, but the function of each separate organ is extremely simple ; while in the lowest polypi, the reverse is the case, they having a single cavity, a simple organ, performing complicated functions. In the intermediate types of the animal kingdom every variety between these two extremes may be observed. And, though the gradation is not absolutely regular and uniform on account of the tendency in each type to attain a higher and higher development in its own peculiar direction, and on account of some peculiar adaptations, as in

the case of the carnivora as compared with the herbivora; still, as a general rule, we have, as we ascend from the lowest to the highest types, an increasing distribution of the functions among a variety of diverse organs; and as we descend from the highest to the lowest, a tendency to concentrate the various functions upon a single organ.*

If now the four great divisions of the animal kingdom be compared with each other, with reference to the tubes which contain and circulate the nutrient fluids, it will be seen, that in man there are *three* distinct sets of such tubes; one consisting of the stomach, duodenum and small intestines, with their glands and glandular diverticula; another, consisting of the lacteals, mesenteric glands and thoracic duct, with the connected lymphatic system; and another, consisting of the veins, right auricle and ventricle, pulmonary vessels, left auricle and ventricle, arteries, and the capillaries. These three sets of tubes, with some modifications in their details, are found throughout the whole type of vertebrata. But, at the other extreme, in the radiata, we have only *one* set of tubes, all opening freely into each other, being, indeed, but ramifications of one central cavity. We have, even, in some of the lowest polyps, only the central cavity itself, without branches, the fluid contained in this cavity being circulated around its walls by their contractions, very much as the contents of the stomach are moved about in that organ by its contractions. In the intermediate types, and especially in the great division of articulata, there are *two* sets of tubes, a set of digestive tubes, and a set of vessels opening into each other and containing only chyle; the two sets, however, being distinct from each other, and only connected, as the intestines and lacteals are in the human system.

Thus throughout the whole great division of vertebrata, of which man is the highest type, there are *three* distinct sets of vessels, the chymiferous, the chyliferous or lymphatic, and the sanguiferous or blood-vessels; the next lower divisions, the articulata and mollusca, have only *two* sets of vessels, the chymiferous and chyliferous, the bloodvessels not existing in these types; while the radiata have but *one* system of vessels, the chymiferous, both the chyle- and blood-vessels being wanting in this type. While, therefore, in the highest division, the food is transformed successively into chyme, chyle, and blood, before it is presented to the various tissues for assimilation and nutrition, in the divisions next below, it is

* It is true that the lower animals have, often, a large number of organs. Multiplicity of parts is one of their characteristics; but it is multiplicity of similar parts. They have many organs identical in structure, and with identical functions. This is wholly different from the many diverse organs, each having its peculiar function, which has been mentioned as so characteristic of the higher animals.

transformed into chyme and chyle before it is prepared for the nutrition of the body ; and in the lowest division, the process of elaboration extends only to the formation of chyme. The circulation of the vertebrata is thus a circulation of *blood ;* that of the articulata and mollusca is only a circulation of *chyle* ; while that of the radiata is still lower, a circulation of *chyme* mingled with water.

These facts, which have recently been brought out* in their relations to each other, by extensive comparisons of the various types of the animal kingdom, have led me to a series of inquiries concerning the relation of the respiratory function to nutrition, which seem to be of sufficient importance to warrant some special investigations. It will be impossible within the appropriate limits of this essay to give more than a mere sketch of this train of thought.

On considering the results arrived at by such a comparison of the circulating fluids of the different types of animals, this most striking and interesting fact at once presented itself—that the nutrient fluid, whether it be in the form of blood, chyle or chyme, whether it be more or less highly elaborated, must first be aërated in the respiratory organs before it is prepared to subserve its appropriate purpose in the animal economy. This is true of all animals.

There is, in this respect, a remarkable uniformity, throughout the whole animal kingdom as compared with the diversity of the fluids which has just been noticed. Although there are five distinct plans of structure of the respiratory organs (two in the type of vertebrata, and one in each of the three inferior types), no one of which is in any way homologous to either of the others, and though these organs are variously modified to adapt them to a great variety of circumstances, still, with all this diversity and variety, they are perfectly uniform and identical in one respect. They are all so constructed, that, in them, the circulating fluid is brought into the closest relation with the air, or aërated water, the very thin membrane generally intervening, presenting no obstacle to the most perfect interchange of influences. So that, in all animals, from the highest to the lowest, the nutrient fluid is subjected to the action of oxygen by being brought virtually in contact with it in the respiratory organs, before it is prepared to minister to the higher function of nutrition.

The chyme and chyle of vertebrata are each perfect in their kind without the agency of the respiratory function, while the blood must be acted upon by oxygen before it can be assimilated ; but in the next lower type of animals, though the chyme can be perfected without the

* By Professor Agassiz.

aid of respiration, their chyle is not fitted for assimilation, until after this indispensable function of respiration has intervened; while, in the lowest class, even the chyme requires to be subjected to the influence of oxygen before it is perfectly adapted to the nutrition of the body. In all animals, therefore, the nutrient fluid, be it blood, chyle or chyme, must be aërated before it can be assimilated.

Physiologists have hitherto supposed that this aëration of the blood has principal reference to the maintenance of a due degree of animal heat. With this, the decarbonization of the blood has been connected as subsidiary to it, or as also having an importance of its own in purifying the blood of a poisonous element. One or both of these offices of respiration have been insisted upon as constituting the essence of this function, and have been discussed at great length. The relation of the respiratory function to nutrition has either been overlooked, or barely mentioned, or, at most, briefly and doubtfully discussed. This is unquestionably in a great measure owing to the fact, that in this, as well as in other departments, physiology has been studied with exclusive reference to the human system, or with some occasional references to other vertebrated animals, all of whom circulate blood containing red corpuscles. It is only in a few rare and more recent instances that comparisons have been freely extended into the inferior divisions of the animal kingdom.

But certainly there can be no reasonable objection to going to the invertebrated animals for light upon this or any other question in human physiology. On the contrary, such extensive comparisons are of the utmost importance and will lead to the most valuable results. It is true, that their plan of structure is entirely different, that there is no homology whatever between them and the highest type to which man belongs. It has been satisfactorily shown that each of the four great divisions has its own peculiar plan of structure, having, in this respect, nothing in common with the others. So that, while we may compare the legs, wings and fins, of the various classes of vertebrata with each other with reference to the plan of structure, we cannot make the least comparison, in this point of view, beyond the limits of each great division; we cannot compare the feet of man, of insects and of starfishes, with each other. Still less can we compare the wing of a bird with the wing of an insect, the former being a modified leg or arm, the latter being a modified lung. So the penis of a lobster is a modified leg, which is not the case in any vertebrated animal. And the eye of a crustacean corresponds homologically to the end of his claw, but the eye of man cannot be in any way compared to the tip of his finger. So that the plan of structure of each great division is peculiar to itself, and

in no way related to either of the others, or comparable with them. We cannot advance one step in reasoning from the organs of the invertebrata to the organs of the vertebrata in this point of view. This has long since been settled, and is now beginning to be generally admitted in practice.

But not so with the functions of animals. Here they come together and can be compared with each other. They all alike consume oxygen and give out carbon ; they all consume and contain within themselves more or less of nitrogenized compounds ; the law of cell life and cell action is common to all, as all originate in cells, their elementary tissues are formed from cells, their functions are carried on by the agency of cells. In all the four great types, we find the functions of locomotion, prehension, deglutition, digestion, circulation, respiration, nutrition, reproduction. Even their various organs, though so diverse and distinct in their plan, approach each other more or less nearly, often very nearly, in their mode of adaptation to perform the same function. For instance, the gills of vertebrata, of articulata, and of mollusca, though formed upon three perfectly distinct types, are, yet, very closely allied in their form, and in the manner in which they are adapted to this common function. In this respect, therefore, the law of the four great divisions of the animal kingdom appears to be—utterly diverse types of organs, similarly modified, for identical functions ; or, organs, typically diverse, morphologically similar, functionally identical.

Therefore, while we are not permitted to reason from the invertebrated animals to man with reference to the plan of structure of the various organs, we may reason from the lower to the higher classes with reference to the great functions common to all, and avail ourselves of the light which the phenomena of one type throw upon the more obscure and complicated phenomena of another.

The great advantage to be gained by extending the domain of comparative physiology to the whole animal kingdom, and studying human functions, by the light poured upon them by an observation of the functions of the lowest animals, is apparent from the fact, that there are among these lower animals, some which are perfectly transparent, and so small that they can be brought under the microscope and kept there in a living state while all the functions of life are going on ; and not only all the minute details of the tissue, but each organ while in the actual exercise of its function, can be brought into the focus of the microscope, and there deliberately studied. Moreover these animals are, some of them, composed of unmodified cells, the muscles, for instance, being bundles or rows of contractile cells, and the nerves being strings of peculiar

sensitive cells ; so that, not only can the living organ be observed while performing these functions, as if the human heart or stomach were placed for hours under the eye of an observer looking through a window in the chest or abdomen, but the separate cells themselves are caught in the very act of living their cell life, and working out their peculiar cell functions.

No one, therefore, can question the propriety, and even the immense importance of studying human physiology in the light thus thrown upon it. And here a door is thrown open to new and wonderful chambers of our science which have remained hitherto unexplored, and which probably contain more valuable treasures than any that have yet been brought to view.

Without pretending or attempting, at the present time, to bring forth any of these hidden treasures, I may yet be permitted to avail myself of the simple and now obvious fact, of the diverse circulation and uniform and universal respiration of animals, to obtain, if possible, some light upon the true office of this latter function.

The idea generally entertained by physiologists, that respiration has special, if not exclusive, reference to the production of animal heat, has already been adverted to. The red corpuscles, or blood disks, have been supposed to be particularly related to this function of calorification. But here we at once meet with the striking fact, that the red corpuscles are wanting in the invertebrata. They have no blood, but only chyle or chyme. And in exact correspondence with this, we meet with the no less striking fact that they are cold-blooded animals, being, in a state of rest, absolutely cold, having no independent heat of their own, but receiving their temperature from the surrounding medium, and varying with it in all its changes. The fishes and reptiles, indeed, have also been called cold-blooded animals, but improperly. They do not, it is true, maintain a uniform temperature within themselves independently of, and in opposition to, the element in which they live. Their temperature varies with that of the water, for instance ; but still, by their internal sources of heat, it is maintained above that temperature, often considerably above it. All the vertebrata, therefore, are warm-blooded animals, all have also red corpuscles, while the reverse is the case with the invertebrata, in both these respects. This settles the question, and shows conclusively that the primary office of respiration is not the production of animal heat. It has a more universal, more important office than this. The production of animal heat is only a secondary adaptation of this function to meet the wants of only one of the four great divisions of the animal kingdom.

But there is another view of this subject, bringing us to the same result, and thus confirming the above conclusion. Most of the lower animals are of so small size, and, being placed in water (a medium which has so direct and powerful an influence in reducing them to the same temperature with itself), are so surrounded, and often filled and even permeated by this fluid, which, in the radiata, actually mingles in large quantity with their digested food, that they must of necessity remain always very near the temperature of the surrounding medium, even if they had sources of heat within themselves. In such animals calorification cannot be the great end of the respiratory function. If it were so, then, in a vast majority of cases, this universal and all-important function would be virtually reduced to nothing. It must have a higher end.

But again, these lower animals, and especially such of them as live in fresh water, vary in temperature with the media in which they live, often to a very considerable extent, being sometimes near the freezing point—at other times more than 50° above. And though some particular temperature may be best adapted to each of them, still as many of them can live an active life at a temperature of forty, fifty, sixty and even seventy degrees, it is obvious that the little the temperature of their bodies could be raised above that of the water at forty or fifty degrees, would be of no very great importance. There must be some more important end for the function of respiration in their case, than the promotion of animal heat. This argument will apply even to the case of the fishes and reptiles, though they are warm-blooded animals, and their respiration has a calorifying object. For, in them, this adaptation is reduced nearly to its minimum, and they are approximated in this respect, very closely to the lower animals. The temperature of the fresh-water fishes varying so much with that of the water, and being never raised many degrees above it, it is obvious that the production of animal heat cannot be the chief object of their respiration.

Indeed, if we confine our view to the case of man alone, now that we have derived the idea from a comparison of the lower animals, we may judge that respiration has a higher end than calorification even in his case. Why is his respiration and circulation so much quickened by active exercise ? Is it because more heat is required ? by no means. And, on the contrary, why is not his respiration equally, or rather, more accelerated when he passes from a warm into a cold medium, if the production of animal heat be the chief end ? And more than all, why is it that any considerable elevation of the surrounding temperature so much accelerates the respiration, when it ought rather to be retarded, if the production of animal heat is its only, or its chief, or even a primary ob-

ject? This phenomenon is still more striking in the lower animals, the temperature of whose bodies is subject to so much variation, and in whom the respiratory function is more limited and less energetic. The respiration of fishes, for example, is very much hurried as the temperature of their bodies is raised with that of the surrounding water, and at length, when they become very warm, in hot summer days, they are often obliged to come constantly to the surface to obtain larger supplies of oxygen, by exposing their gills to the influence of the atmospheric air. Is this for the purpose of increasing their animal heat? or has this function a higher end,* the urgency and importance of which, at these times, quite transcends the subordinate one of calorification, so much so as actually to increase the animal heat, when it is already in excess, and needs to be diminished rather than increased.†

It may, therefore, be regarded as a settled point, that respiration as a function of organic life has another and a higher end than the mere production of animal heat. That in man with his blood circulation, with red corpuscles, and maintaining a uniform and independent temperature, this is an important secondary adaptation of this function, there can be no doubt. But its great, fundamental, office, essential to organic life under all circumstances, and existing universally throughout the whole animal kingdom, must be and is something different from this. What then is it?

The second and remaining answer, that has usually been given to this question, is, that respiration is essentially a decarbonizing process; the lungs and gills being excretory organs, serving to remove the useless carbon from the system. That, in man, this actually takes place to a great extent, is unquestionable. The same is true in the other types of vertebrata, though, in some of them, to a very limited extent. Many invertebrata also are known to give out carbonic acid in considerable quantities, when in a state of activity and excitement. The chemist is needed to make further and more minute and careful investigations. It may, perhaps, prove true that respiration always removes more or less carbon from the system, and that the various kinds of lungs and gills have originally and in their essential nature an excretory function connected with their other functions. The fact, however, that we have

* The elevation of the temperature accelerates all the vital functions. This increased activity can only be sustained by larger supplies of nutrient material, which must be aerated in order to its complete elaboration. Hence the urgent demand for more oxygen even at the expense of the excessive heat which must thus be incidentally produced. See subsequent pages of this essay.

† It should be noticed in this connection that young animals consume much more oxygen than older ones, while their animal heat is not materially greater. Their vital functions, however, are in a much higher state of activity, and demand more nutrient material.

already a special organ, the liver, as an outlet for the useless carbonized elements of the blood, just as there is a special organ, the kidneys, to serve as an outlet for the useless nitrogenized elements, may raise a doubt whether the elimination of carbon is really one of the final objects of respiration. Moreover, it is certain that the *large* elimination of carbonic acid by the lungs of man and the higher animals is merely incidental to the calorifying function, it being necessary to remove from the body the carbonic acid formed in the process of maintaining animal heat. It is not a universal and necessary part of the function. But it is this large formation and excretion of carbonic acid, connected with the calorifying process in the higher animals, that has produced the prevailing impression with regard to the importance of this excretory part of the respiratory function. There is reason to believe that the small amount of decarbonization, which may be found connected with the respiration of the lower animals, is, also, only an incidental circumstance attending upon the primary office of this function. But even granting that decarbonization may be in itself one of the ends of respiration, and not a mere sequence of some more important process, is it *the* great end, or is there another and a higher one? The way is now open for an answer to this question.

What, then, is the great end of respiration? Does it sustain any relation to nutrition? Is it indirectly or directly subservient to that perfect elaboration of the nutrient fluid by which it is fitted to build up the tissues, and sustain the organs in all their vital functions?

Indirectly, it is subservient to nutrition, in the higher animals, by the very maintenance of the appropriate degree of animal heat. It is not in inorganic chemistry alone that heat promotes energy and intensity of action. In vital chemistry, in living functions, the same phenomena are observed. While a certain degree of heat is best adapted to the healthy and vigorous activity of each animal, a lower degree will retard it, even to the stagnation observed in the hibernating state; and a higher degree will accelerate the vital functions to an extent incompatible with the preservation of life for any length of time. Animals under such circumstances live too fast, and soon wear out. This is especially seen in the lower animals who are dependent upon the surrounding media for their temperature. But the higher animals are not thus dependent. They are constructed upon a plan, which furnishes them with internal resources to resist external influences. The very form and habits of the inferior animals are controlled by surrounding circumstances; the form, habits and life of the higher animals are shaped by a power within them, which often prevails over powerful antagonistic influences from without. The

lower animals are acted upon by the external world; the higher so formed as to act upon it and to mould it to their purposes.* And this independence, this internal energy, is in a great measure owing to their capacity of preserving their proper temperature, amid the changes in that of the surrounding elements. This uniform temperature, exactly suited to the nature of each animal, promotes and secures a constancy, precision and energy in the nutrition of the tissues and in all the vital functions, that supply the animal with resources and power within himself to work out his destiny, in the face of opposing influences in the world around him. Without doubt, too, it promotes those important changes which are going on in the nutrient fluid itself, giving energy, rapidity and precision to all those processes by which it is perfected and prepared for the nutrition of the tissues. Thus the peculiar animal heat of the higher animals is the handmaid of that vigorous nutrition, by the constant self-sustained activity and energy of which they are prepared to meet all the exigencies of their higher condition and are able to mould surrounding circumstances to their wants, instead of being moulded by them.

So, also, respiration may be indirectly subservient to nutrition, in all animals, by its power of removing carbonic acid from the system. The large amount of carbonic acid formed in the higher animals in the process of calorification, if not immediately removed, would exert a most pernicious influence upon all the vital functions by which the nutrient fluid is elaborated and appropriated by the tissues. Indeed it would speedily arrest nutrition and all its subordinate processes. This excretion of so deleterious a substance, has therefore indirectly a most important bearing upon nutrition. The same may be said, though in a lower degree, of the more limited excretion of carbon in the inferior animals.

Moreover, though much of the carbon used in the calorification of the higher animals is derived from a part of their food especially designed for this purpose, a very considerable portion of it is also derived from the decomposition of the tissues. This is probably the almost exclusive source of the carbonic acid given off by the respiratory organs of the lower animals, when in a state of activity and excitement. This activity is only maintained at the expense of the tissues in which it is manifested. They are used up to maintain it. As in mechanics there is no force exerted without loss of power, so in life there is no vital force exerted without loss of material. The old material is used, is decomposed, and new material is substituted, is assimilated. And

* Agassiz.

so far as the formation and excretion of carbonic acid is thus connected with the exchange of old for new material in the tissues, or, in other words, with the nutrition of the tissues, just so far is the decarbonizing function of respiration most intimately related to nutrition. Indeed this would seem to be something more than indirect subserviency.

But, still further, the new supply of nutrient fluid coming directly to the respiratory organs from the digestive apparatus, is, in the higher animals, rich in carbon, and perhaps in all animals may require the removal of some carbon from it, to adapt it to the purposes of assimilation. If so, here would be a still more direct agency of the decarbonizing function in preparing the nutrient fluid for nutrition. Considering respiration, therefore, in this point of view, that is, with reference to the excretion of carbonic acid, it is certainly subservient to the nutritive processes indirectly in a most important way, and probably has even a direct bearing upon the preparation of the nutrient material, and upon its application to the uses of the living tissues. Thus both calorification and decarbonization are not to be regarded as final causes, as the great end for which we breathe ; they are but means subservient to a higher end, and that end is nutrition.

But is it only in these points of view that respiration is to be regarded as subservient to nutrition ? Is it only by maintaining animal heat, and excreting carbonic acid, that it ministers to this cardinal function ? It seems to me that there is a higher point of view to be taken of this connection ; that respiration has a more important office to perform than either of the two which have been mentioned ; that it has nobler work to do than the mere drudgery of preserving the proper temperature and removing useless or noxious substances ; that it is not a mere builder of fires and sweeper of apartments, but is a chief artist in nature's workshop ; that it has a most direct and positive agency in the elaboration of the nutrient materials ; that it puts the finish upon the work of the subordinate functions ; that its office is to bring the vital fluid to a state of perfection, and thus present it to nature ready for her use.

The distinguishing phenomenon of the respiratory process is—the consumption of oxygen. This introduction of oxygen into the system is unquestionably its primary, fundamental office. It is universal, it is everywhere indispensable to life, it is not subordinate or incidental to any other process. The excretion of carbonic acid may, perhaps, prove to be universal, but the large excretion of this substance in the higher animals is merely incidental to the calorifying process, and even the more limited excretion of it in the lower animals, when active, may be considered as chiefly incidental to the decomposition of the tissues ; and it

still remains to be shown, that the carbonized products of the tissues, wasted by vital action, may not be removed from the system of the lower animals by the agency of the liver or some other excreting organ of a similar character. The reception of oxygen into the system is, however, beyond dispute, a universal, a necessary, and a primary or fundamental office of the respiratory function.

And this oxygen is not received into the organs of respiration merely to extract carbon from the blood, by attracting it through the thin walls of the bloodvessels, and air-vesicles, and then passing off with it in the form of carbonic acid. It is now well known that the carbonic acid is formed in the system, and is brought in the veins to the lungs and there thrown off, (and may even be thrown off freely when no oxygen is inhaled), while the oxygen is received into the system and accompanies the arterial blood on its proper mission. It may, indeed, abstract some carbon from the newly-formed chyle, and thus may form some carbonic acid in the lungs; or it may, perhaps, exert there some other influence upon either the new, or the older parts of the nutrient fluid, or upon both; or it may produce some important change in the nutrient fluid as it accompanies it in the arteries; or it may reserve its forces till it reaches the capillaries, and there act directly upon the living tissues. It does not expend its power in the lungs in the formation of carbonic acid, but either acts directly upon the nutrient fluid, or goes with it to act upon the living tissues in all parts of the body. And here it must be remembered that oxygen is one of the most important elements in inorganic and organic compounds, that it is one of the most powerful agents both in natural and vital chemistry.

Now for what purpose is such an agency as this brought to bear upon the vital fluid just before it is ready for assimilation, or even brought to bear directly upon the living tissues? Is it probable that it only enters the circulation and passes round the system as a mere vehicle to take up the useless and injurious particles of carbon and carry them out? Are we sure that the vital energy of the tissues is not competent to this excretion of carbonic acid, as well as of the elements of bile or urine? Is oxygen merely a laborer's wheelbarrow, to be passed up and take its load of carbon and carry it away? Has not this powerful and indispensable element a higher office than this, and one more closely connected with the perfect formation and assimilation of the nutrient fluid, and the vital action of the tissues themselves? There is a most significant fact bearing upon this point—that throughout the whole animal kingdom, the nutrient fluid, be it in the form of chyme, chyle, or blood, must in every case be first exposed to the influence of oxygen before it is prepared for

assimilation; and having once gone round, and returned to the heart, it must again go to the lungs to be oxygenated before it is prepared to be offered a second time for the use of the various tissues. This appears to be the last stage in the process of preparation, and an indispensable one. By this the elaboration of the nutrient material is perfected and it is finally fitted for use.

In cases of death produced by suffocation, or of a depression of the vital actions by this means, it has been commonly supposed that the brain and other organs are oppressed by the poisonous influence of the carbonic acid in the blood. Whatever may be true with respect to the poisonous influence of the carbonic acid, is it certain that this oppression is not in some measure owing to a deficient supply of the proper material for nutrition? If the exercise of vital functions is carried on at the expense of the vital elements composing them, if all vital action involves waste of tissue and depends upon it, may not this oppression be partly or even chiefly owing to a deficiency of appropriate materials to supply this waste, to sustain the vital action of the brain and muscles? This is the more probable, or rather the more certain, inasmuch as these same phenomena of asphyxia are produced by the inhalation of hydrogen and nitrogen, which permit the carbonic acid to pass off freely, but do not supply the blood with oxygen. And not only are the tissues deprived in this way of the perfected nutrient material necessary to sustain their vital action at each moment, they are also deprived of the stimulus to action which such perfectly elaborated material would furnish, and which, perhaps, the oxygen itself may also afford. Thus, on account of the deficiency of oxygen in these cases, there is not that needful stimulus, and that supply of the elements of force, which the active exercise of these functions requires. May not this be one reason why the blood is accumulated in the lungs—not merely because there is a poisonous substance mingled with the blood that is otherwise adapted and sufficient for its purposes, but also because there is a deficiency in the blood itself, a want of that vitality which oxygen would produce in it, so that it cannot now supply the appropriate stimulus to the organs themselves, to the minute vessels and cells of the lungs, to the elements of the nervous, muscular and other tissues, and also cannot supply the necessary nutrient materials at the expense of which the functions must be carried on.

The phenomena of etherization show, that with good aërated blood a substance may be mingled producing a most oppressive influence upon the system without interfering with the more vital functions, thus not destroying vital action, but merely suspending or modifying it in certain

respects. And even though carbonic acid exerts a more powerful and oppressive and often fatal influence, it would seem to be not this, but rather the privation of oxygen, that arrests the vital action and stagnates the living current in the midst of its course, by withholding from the blood and the tissues the influence of that powerful agent by which their vitality is maintained.

That the oxygen consumed in respiration has such an influence directly upon the blood, or the tissues, or both, and is not destined merely to the formation of carbonic acid, is evident from the fact that more oxygen is consumed than is given out in the carbonic acid.

This is especially obvious in some of the lower animals, in which the amount of oxygen consumed is three times as great as that given out in the form of carbonic acid. So that even supposing there is no carbonic acid formed wholly from the decomposed tissues, and that all the oxygen given out in the carbonic acid is furnished by the respiratory organs, there is still an excess of oxygen which can exert the direct influence upon the vital fluid and the tissues referred to above. But it is not at all improbable that a large part of the carbonic acid supplied by the wasting of the tissues in vital action may be furnished wholly in the form of carbonic acid by those tissues. If so, there would be a still larger surplus of inspired oxygen to be applied directly to the perfecting of the nutrient fluid.

I cannot in this essay enter fully into any of these topics. Indeed, my design has rather been to bring forward these questions, which have been started in my mind by a consideration of the recently established facts of the chyme-, chyle- and blood-circulation of the several great divisions of the animal kingdom. Here certainly is a broad field for research upon some of the most important points in physiology.

In the imperfect survey above taken of this field, some things have been stated with a degree of confidence that the facts seemed to demand, but many things have been presented only as questions naturally raised and requiring an answer.

So much, however, may be fairly considered as established :—

That respiration has not exclusive or even principal reference to calorification, but has reference to some more important, universal, fundamental influence upon the animal economy, which may be exerted at any temperature in which organic life can be maintained, and without reference to the maintenance of that temperature ; and that its calorific function in the higher animals is only a secondary adaptation of it to their peculiar circumstances :

That the decarbonization of the blood, even if it prove to be universal

and necessary to life, is a function incidental to other processes, and by no means the primary and essential office of respiration :

But that the cardinal office of respiration is to supply the blood with oxygen, which by its powerful agency may perfect the nutrient fluid and fit it for assimilation, and which may also, perhaps, act directly upon the living tissues, thus having a most direct and intimate relation to the great central function of organic life, nutrition.

Respiration, therefore, does not merely supply a necessary condition of vital action ; it does not merely remove out of the way a pernicious substance ; but it exerts a direct and positive influence of the most important character upon the vital fluid and the living tissues, indispensable to their perfection and vitality, and thus it is a direct, positive source of life and power to the organism.

This view of respiration gives a higher sanction, than has ever yet been given, to some of the most important principles of hygiene and therapeutics, and can hardly fail to give a new impulse to their practical application. It may also shed some light upon certain pathological conditions of the human system.

The value of pure air in connection with the preservation of health is universally acknowledged. Free ventilation, and exercise in the fresh morning air, are abundantly insisted on ; but it has been rather with a view to the removal of deleterious gases, or noxious exhalations, and to obtaining the exhilarating and tonic impression of the fresh cool air upon the nervous system, or from a general and vague impression derived from experience of its beneficial effects, than from any idea of the necessity of a full supply of oxygen to the very *formation* of the nutrient material upon which life and health every moment depend, and to the maintenance of healthy vital energy in all the living tissues. The importance of pure air free from all noxious admixture, and of the healthful tonic influence of the fresh breezes of the morning, of the fields, and of the sea-shore, is not exaggerated. Their value can hardly be overestimated. But if we add to this the fact, that pure air furnishes the very materials out of which life and health are built up, that it has a direct, positive, indispensable part to act in those vital processes, by which they are every moment maintained, then we have something tangible, impressive, directly addressed to the reason, carrying full conviction to the mind, that an abundant supply of pure air is necessary to supply the positive and urgent, and constant demands of the vital organs for oxygen to enable them to maintain a healthy vital action ; that such a supply of pure air is needed, not only in the cool of the morning, on the hill-top, and at the sea-shore, but that everywhere and at every moment

the very wheels of health and life are dependent upon it as the element that supplies the very forces which maintain their movement.

This view of respiration may also shed light upon some important points in pathology. I refer particularly to those scrofulous and cachectic conditions of the system, in which abnormal deposits or malignant growths occur, or in which the reparation of the tissues is retarded or prevented, or their destruction is going on. In addition to the influence of former disease and irregularities, of hereditary tendencies, of unhealthy food, of uncleanliness, of exposure to hardships and privations, of inaction and confinement, of mental dejection and passion, &c., the influence of bad air and imperfect ventilation in producing and aggravating these diseased conditions is well known. And if instead of a vague notion of poisonous gases and unhealthy exhalations, and general depression of the vital powers, we are able to substitute the more definite idea of a direct deficiency of an element most essential to the perfect elaboration of the material supplied to the tissues for assimilation, we certainly approach nearer to a comprehension of these pathological phenomena. If we can once but know that a deficiency of pure air renders it impossible for the nutrient fluid to be perfectly prepared for the wants of the system, that on this account it fails to be formed into a perfectly plastic material, then, in this cacoplastic substance offered to the tissues for assimilation, we see one important cause of those abnormal deposits which not only prove insufficient for the purposes of the vital economy, but are often so destructive to its health and life. Here the value of pure air for respiration to all who would avoid or check such diseased tendencies in the system appears in a new and striking light, placing before all such persons a most powerful and urgent motive to secure for themselves constantly a good and abundant supply of this indispensable element of perfect nutrition.

But above all, this view of the function of respiration shows in a new and clearer light, how indispensable to the physician, as a means of cure, is a constant supply of pure air to his patient. It even suggests the inquiry whether the inhalation of a more highly oxygenated air may not be of great service in some cases. It is not improbable that, since the inhalation of ether has exerted so potent an influence, and has proved such an inestimable blessing to suffering humanity, the virtues of other gases applied in the same way to the respiratory organs may also be tested. Dr. Beddoes's inhalations of vital air, which many years ago were represented as rendering such effectual aid in the cure of certain diseases, may now be repeated with the most valuable results.

But however this may be, the value of pure air to the sick as well

as to the healthy, will not be denied. Indeed, it is to some extent insisted on, though there is reason to fear that it is less regarded in the private chamber of sickness than in public institutions. In our Hospital* its importance is acknowledged; the valuable results are clearly seen. It is probably as much owing to the good ventilation of this institution as to any other cause, that the type of disease generally exhibits such a decided improvement immediately after the admission of the patient.

That such must necessarily be the result, from the very nature of the case, is evident, when we consider the important office assigned to respiration in the vital economy. If diseases are to a great extent self-limited; if there are few specifics in medicine; if we cannot drive the elements of disease from the system, by our drugs; if we must rely mainly upon the vital powers themselves as exerted in the various organic functions; if by promoting the free, healthy, unobstructed exercise of these functions in all cases we can best aid nature in her work of the restoration of health; if a constant supply of perfectly elaborated nutrient material is necessary to maintain those vital processes by which she does this great work; then it is indispensably necessary that the agent which God has provided to perfect this elaboration of the blood, should be constantly supplied to the patient in free, full draughts of the pure air of heaven. It is especially wrong to withhold from nature full supplies of force and natural stimulus in the very hour of her necessity, when all her powers are tasked to the utmost in the struggle to throw off disease. The evil effects of such privation are as natural as they are obvious, and the happy results witnessed at our hospital, when this vital element in its purity is reädmitted to the lungs of the sick man, are in strict accordance with the laws of life.

The paramount importance of pure air in sickness as well as in health might be inferred from its universal diffusion. The most valuable gifts of God to man are the most common, though, too often, least highly prized. Iron is of more value than gold; coal is worth more than diamonds; and the dirty despised soil of our fields and pastures is worth more to man than all the produce of the mines. Wheat is of more value to us than the most rare and luscious fruits; water has virtues far surpassing those of the choicest wines. But more precious still is the pure ethereal element, and being so, it is more lavishly bestowed by the bounty of providence than all the rest. Everything else, even water itself, though placed within our reach, can be obtained only by exertion on our part; but this is poured out upon us, and

* Mass. General Hospital, Boston.

made to flow all around us, and within us, by the hand of God himself without any effort of our own. In it we live, and move, and have our being. Everything else we can dispense with for minutes, for hours, even for days, but this we must have every moment or we die.

In such infinite profusion of this great gift to humanity, and in its importance to our very existence, there is a deep significance. Here is a lesson, not for the moralist alone, but for the physician—a lesson which he should make haste to learn, fraught as it is with instruction from the lips of infinite wisdom. The Creator of the human frame having thus shown us his estimate of the comparative value of this great agent in maintaining those vital functions by which the life and health of the organs are preserved or restored, we should make full and free use of what he has thus revealed to us as nature's grand restorative.

In speaking thus strongly of the supreme importance of this agent as a means of cure, I would not be understood to undervalue other remedial agents. On the contrary, I would place a higher estimate upon the ordinary medicinal agents than is now generally accorded to them. In this city, at least, it seems to me that the pendulum of professional opinion is swinging to the extreme of too little confidence in the power of medicines. Many of those agents which we draw from the animal, the vegetable and the mineral kingdoms, have great power over the functions upon which life and health depend, stimulating, moderating, sustaining, invigorating, modifying, and even altering them, to a very remarkable degree. Some of them seem to have even a specific control of certain diseases. It is not that I prize these less, but that I value pure air more. Yet some, even of our best physicians, seem practically to overlook its importance. They are too often satisfied with a correct diagnosis, and a judicious prescription, leaving the patient to struggle on in the confined air of his chamber at the discretion of his nurse, or with a passing remark that "it would be well to have more air;" not insisting upon this latter as an all-important thing that must not be neglected, but must be fully and faithfully attended to. I would not object to the most heroic remedies when they are indicated. In certain cases the physician should be a very knight-errant of medical chivalry. Yet even in such cases, nature's indications with regard to pure air would never be forgotten.

But especially in those more protracted struggles of nature with her enemies, when her powers fail, when she is languishing and exhausted, should the physician secure the full and unceasing action of that great agent, which divine Wisdom has prescribed and which the divine Hand itself administers. Too often, when the exhausted powers of the system cry out to the physician for that wholesome aliment which can furnish

sustenance to their wasting energies, he gives them that which can afford them no nutriment; when they ask for bread to minister to their nutrition, he gives them a stone to oppress them. Too often, when they beseech of him to allow free access to that living, life-giving element upon which their vitality depends, he offers them only some pain-giving, poisonous, blistering agent; when they "ask for an egg he gives them a scorpion." But the physician should always freely give the pure breath of heaven to struggling nature when she pants for it. At no time should its value to the sick man be forgotten; at no time should it be left to the carelessness of the nurse, or the foolish prejudices of friends. The physician should feel the weight of this responsibility as resting upon himself and see to it that this chief of all the restorative agents of nature is faithfully employed. And at those times, when languid and exhausted nature more especially needs its aid, to strengthen and quicken her for a more successful struggle, should he insist, with an energy that will command obedience, that it have free access to his patient fresh from its native skies.

In nature's great extremities, when her powers flag in the swoon, or ebb away at the approach of death, we instinctively throw open the door or window, or carry the sufferer to the open air that he may feel its reviving influence. Here unerring instinct teaches, when reason fails. Why not do the same when the powers are more slowly flagging, and life is more slowly ebbing away in the sick-room, perhaps from the very need of this refreshing and vivifying influence. How often is pure air, in connection with wholesome food, proper exercise, and cold water, and before them all, the sheet anchor of expiring hope. What means shall we, in such cases, resort to, to supply, to invigorate, to preserve life in the still living body? This living, life-giving element, rightly called vital air, can alone give life to the living blood and the living tissues,

> "Leben dem leben
> Gibt er allein."

In no way, therefore, can the good physician do more to restore the sick to health again, especially in many of those cases which call for all the resources of his art, in no way can he confer a greater blessing upon his patient, than by seeing that this and the kindred duties of the nurse are faithfully attended to; by securing for his prostrated system the full influence of that great restorative which his Maker himself has provided for its necessities in such abundance; by calling down the fresh breezes of heaven to fan his brow, to play around his mouth, to reach the very citadel of life, carrying with them all their invigorating, and life-giving power.

NOTE.

Dr. Carpenter is one of the few and more recent physiologists (referred to on page 4 of this Essay), who have freely extended their comparisons into the inferior divisions of the animal kingdom. The earlier editions of his works on "comparative" and "human" physiology were marked by this characteristic, and are indebted to it for much of their merit. Yet, after all his comparisons of the higher and lower animals, he treats of this function merely as a calorifying and decarbonizing process. He barely *alludes* to the fact that oxygen is also necessary to give the blood its power to nourish and stimulate the tissues—that, without it, this fluid is not fit for its normal action.

But in the third edition of his "Comparative Physiology," 1851, he has availed himself much more largely of the respiratory phenomena observed among all organized beings, and his conclusions correspond to a considerable extent with those of the preceding Essay.

He shows (§ 441) that the "crude aliment must be exposed to the air before it is fit for its ultimate purpose," and that which has once passed through the tissues must undergo a similar process to restore it to its proper condition;" that the "presence of oxygen is necessary to the active performance of the animal functions by the nervo-muscular apparatus;" see also § 451—that it is "essential (§507) to the changes of the tissues in the development of muscular force and nervous energy"; and is "one of the conditions (§235) of muscular contraction"; see also §236.

In §§67, 494, 509, and elsewhere, he treats very *fully* upon this subject, showing that oxygen has a direct and most important agency in the processes connected with the growth of the tissues, their decay and reconstruction, as well as with the development of muscular and nervous activity (why not of *all* vital action ?)—showing also that its presence and influence is necessary to the generation and transformation of the organic compounds contained in the circulating fluid and constituting its nutrient material, and he refers to the conversion of starch into sugar, and of albumen into gelatine, as instances. Speaking of this use of oxygen, he considers it (§67) as properly entitled to the name of *food*.

Such views of the nature of the respiratory function are of the highest importance, and will be more fully developed in their scientific and practical relations, as the functions of all animals are more extensively and thoroughly investigated—the phenomena, thus observed, more carefully compared—and their significance more deeply studied, in their relations to life, health, disease, and restoration.